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HIGH DENSITY Z-PINCH PULSE-POWER SUPPLY SYSTEM TITLE:

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HIGH-DEASITY Z-PINCH PULSE-POWER SUPPLY SYSTEM®

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Abstract

The design and operation of the high-density Z-pinch experiment pulse-power supply is discussed. A 600-kV, 1-MA, 75-nH Marx bank is designed to charge a $1-\Omega$, 90-ns, water-insulated transmission line to -0.6-1.0 MV. The water line is then discharged through a small laser-initiated current channel in 1-5 atm of hydrogen. The components of the marx bank, the trigger system, the water line, and the gas load as well as the control system that uses fiber optics and air links for monitor and control are discussed.

Introduction

The high-density Z-pinch (HDZP) experiment at Los Alamos Scientific Laboratory has been constructed to investigate the plasma parameters of a laserinitiated current channel in a high-pressure gas. A 1-GW neodymium glass laser is used to initiate a conducting channel with a diameter radius on the order of 100-200 µm between two electrodes spaced from 5 to 10 cm apart as shown in Fig. 1. The pulse-power supply ideally must produce a rapidly increasing current and thus magnetic field to prevent expansion of the ohmically heated plasma. Simple models indicate that plasmas with densities on the order of 1020 cm-3 can be heated to several kiloelectron volts with this system. A prototype system was constructed to develop hardware for a larger experiment. This paper discusses the main HDZP system.

Pulse-Power Supply Design

The theoretical current waveforms, determined from a very simple model, that are required for mainWork performed under the auspices of the US
Department of Energy.

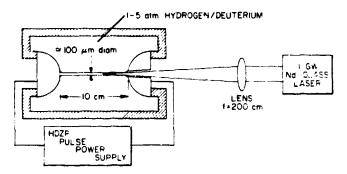


Fig. 1. Schematic of HDZP system.

taining a constant channel radius for three filling pressures are shown in Fig. 2. The gas load has an inductance on the order of 100 nH. In order to obtain the desired \hat{I} at channel initiation of $\sim 0.5-1.0 \times 10^{13}$ A/s, the initial voltage across the load must be $\sim 0.5-1.0 \times 10^6$ V. The maximum current required from the power supply is on the order of 1 MA.

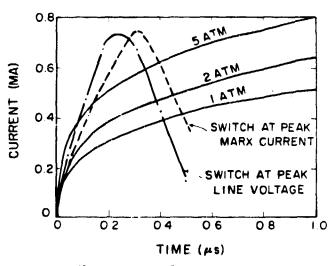


Fig. 2. HDZP current waveforms.

Several circuit configurations were evaluated and simulated using the NET 2 circuit analysis code. A system consisting of a water-insulated, intermediate storage line resonantly charged by a low-inductance Marx was chosen as the most versatile system. The basic circuit for the HDZP system is shown in Fig. 3. The system can be operated with a wide range of current risetimes and current amplitudes by laser initiating the current channel at various times during the resonant charge of the water line. The water line provides the initial high rate of current rise. The energy remaining in the Marx capacitance and the energy stored in the resonant-charging inductance provide gas load current at later times.

The HDZP water line was designed such that the impedance could be varied from 0.25 to 1.0 Ω with a transit time of 90 ns. The maximum line voltage and load current are determined by the time of current channel initiation, the Marx charge voltage, and the water line impedance. The current waveforms produced by simulation of the HDZP system are also illustrated in Fig. 2 with dashed lines.

Marx Bank Design

The HDZP Marx system was designed to have a minimum inductance, to operate at a nominal 500 kV output voltage and to deliver 1-MA peak current. The minimum energy store of the Marx is determined by the maximum desired inductive load energy of about 50 kJ. In order to accommodate the maximum Marx current and reduce the Marx inductance, 12, 6-stage Marx modules, each of which stores 4.3 kJ at 500 kV and provides a maximum fault current of 83.3 kA, were paralleled. The individual Marx module circuit diagram is shown in Fig. 4 and pictured in Fig. 5. Each Marx module stage consists of two parallel

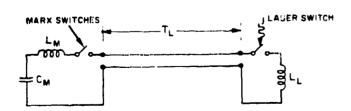


Fig. 3. HDZP circuit schematic.

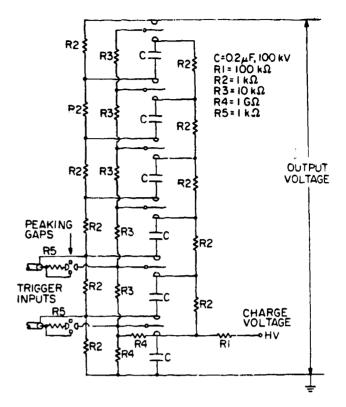


Fig. 4. HDZP Marx module schematic.

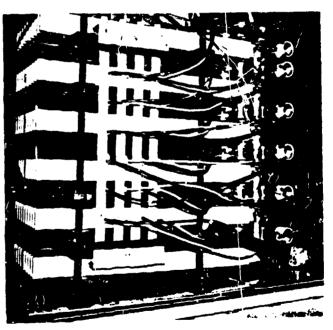


Fig. 5. Picture of Marx module.

0.1 μF , 100-kV Maxwell series S capacitors and one Physics International T670 triggered spark gap. Each capacitor has a maximum rated current of 50 kA, and the spark gap has a maximum rated current of

100 kA. The capacitors were specified with 50% voltage reversal to accommodate a Marx output fault and resulting 75% voltage reversal at 500-kV output voltage. The Marx bank inductance at the output terminals is 75 nH. However, the transition section between the Marx bank and the water line increases the total series inductance to about 250 nH.

The Marx trigger system was designed to erect all the Marx modules in a small fraction of the minimum voltage rise on the water transmission line or within ~20 ns. The trigger circuit chosen is shown in Fig. 6. This trigger Marx arrangement is a variation of trigger circuits suggested by Fitch and was selected because the trigger pulse of the Marx module gaps can be controlled in amplitude, risetime, and arrival time very precisely. In addition, each Marx module spark gap can be triggered with a similar trigger pulse without loading the Marx system. The simultaneous trigger pulses are generated by shorting 12 coaxial cables charged to a maximum of 100 kV with a spark gap that also serves as the trigger Marx stage gap.

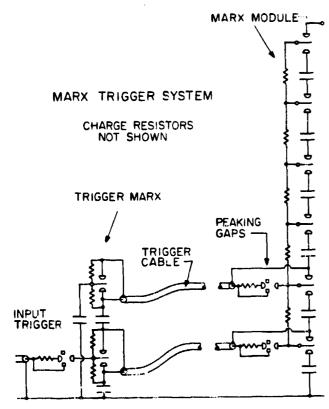


Fig. 6. HDZP trigger system schematic.

In order to minimize the jitter in erection of the main Marx modules, the trigger pulses provided by the trigger Marx must have a risetime less than the desired scatter. The 12 cables that are shorted by the trigger Marx stage gap have a characteristic impedance of about 36 Ω each or a parallel impedance, $\mathbf{Z}_{\mathbf{p}}$, of 3 Ω . The trigger Marx gap inductance, L_{G} , must be such that L_{G}/Z_{D} is on the order of 5 ns. This requires a trigger Marx gap with an inductance of about 15 to 20 nH, which operates at 85- to 100-kV dc and is easily triggered. The final design of the trigger Marx gap is shown in Fig. 7. An acrylic sheet insulator is designed to minimize tracking within the gap. The gap operates at an SF6 pressure of about 60 psig for a 100-kV charge.

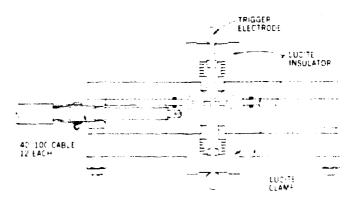


Fig. 7. Trigger Marx low-inductance spark gap.

The trigger Marx stage capacitors serve to bias the shorted cable trigger generators at a potential similar to that of the main Marx and to isolate the main Marx stage voltage from ground. A 2-stage trigger Marx that triggers only the first 2 stages of the 12 Marx modules is used because initial tests indicated additional stages are unnecessary. The coaxial trigger cable charge voltage is isolated from the main gap trigger electrodes by an "insideout" trigatron peaking gap. The peaking gap shown in Fig. 8 also reduces the trigger pulse risetime seen by the main gap trigger electrode <7 ns with a jitter spread of <2 ns. The 2-stage trigger Marx is initiated by an 8-stage ceramic capacitor micro-Marx generating a 200-kV pulse with risetime of <20 ns and a jitter <2 ns. The micro-Marx is shown in Fig. 9.

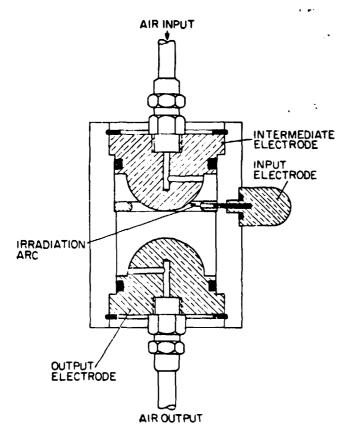


Fig. 8. Trigger system peaking gap.

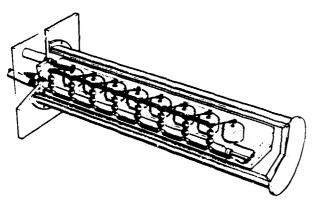


Fig. 9. Trigger micro-Marx.

Transmission Line Design

The water-insulated transmission line system is shown in Fig. 10. A parallel-plate transmission line was chosen over a coaxial transmission line for two reasons. First, the impedance can be easily varied by changing the number and size of the parallel plates. A large water tank was designed to hold the transmission line leaving a large amount of room for line variations. Secondly, the local-

ized nature of the laser-initiated plasma channel requires storing the pulse energy very close, physically, to the center line of the pinch channel to reduce the transition inductance. A disk transmission line with radial Marx current feed would be the optimum configuration, but building space limitations prevented using this design.

Gas Load

The desired characteristics of load geometry at the end of the water transmission line are a minimum inductance configuration, a uniform electric field distribution in the pinch region, and visibility and maximum access for diagnostics. The present gas load is shown in Fig. 11.

Control System

The control system for the HDZP experiment is completely isolated using only fiber optic links or air links for control or monitoring system operation. The major types of links are illustrated in Fig. 12. The power supply voltages, power supply currents, and capacitor bank voltages are monitored using the fiber optic link of Fig. 12a. A voltage divider or current monitor provides a voltage from 0-10 V to a voltage-to-frequency converter that modulates a LED from 10 Hz to 10 kHz. At the other end of a fiber optic cable the light pulses are detected and converted back to a voltage/current, which operates a standard trip meter. Those functions that do not require precise time operation are

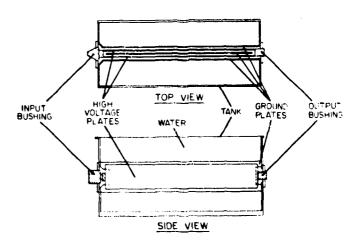


Fig. 10. Water-insulated transmission line.

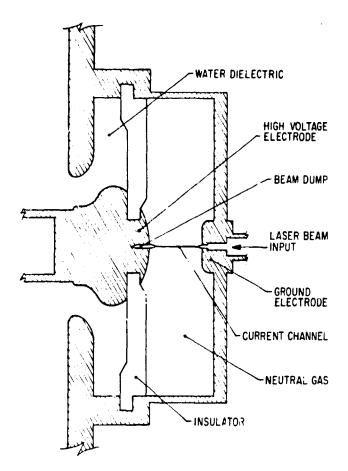


Fig. 11. HDZP gas load chamber.

implemented using compressed air, one example of which is shown in Fig. 12b. The nigh-voltage dump and safety switches are also actuated using air links as illustrated in Fig. 12c. The interlock systems are structured as shown in Fig. 13. Each location or function requiring an interlock was designed to provide closure of contacts, energizing a high-intensity lamp. The resulting light is conducted to the main control panel through a fiber optic cable where a phototransistor pulls in a relay if the high-intensity lamp is energized. This method is very simple and has been extremely reliable. It is fail safe in that a malfunction prevents relay closure and inhibits system operation.

The trigger system also uses fiber optic links from the time delay system in the screen room to various systems to be initiated. The trigger link system is diagrammed in Fig. 14. The basic timing system consists of a multichannel digital time delay unit that determines the timing sequence of the experiment. The time delay output signals energize injection laser pulsers, which produce 900-nm light

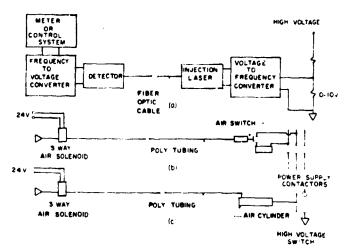


Fig. 12. HDZP control systems.

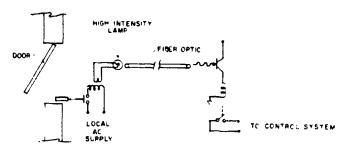


Fig. 13. HDZP interlock system.

pulses that are conducted to the various systems in the HDZP experiment through fiber optic cable. The receiver-pulse generators shown in Fig. 14 produce electrical pulses at voltages from 5 to 900 V with 10 ns risetimes and various pulse lengths and shapes. The jitter of this type of trigger link system is less than il ns. The system is extremely insensitive to the large amount of EMI present and the location of the fiber optic cable in the experiment is thus not critical.

System Operation

System operation is initiated by charging the Marx bank and charging the trigger Marx such that they reach the desired voltage simultaneously in about 30 s. The control system monitors bank voltages and sends a fiber optic trigger pulse into the screen room after disconnecting the power supplies. The digital time delay system then energizes the appropriate systems in the proper sequence. The main Marx is erected to pulse charge the water line in about 200-600 ns. At the desired load voltage the glass laser initiates the HDZP current channel and

at the desired time various diagnostic lasers are initiated. The jitter is erecting the Marx to charge the transmission line is ±10 ns. The water-insulated transmission line uses self-break water switches to "crowbar" the Marx bank and reduce the Marx capacitor reversal. The system has been tested to a charge voltage of 100 kV per stage, although the Marx system was designed to operate at a charge

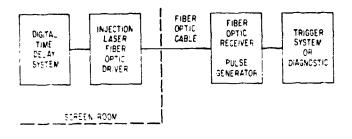


Fig. 14. HDZP timing system.

voltage of 85 kV per stage to allow for various fault modes. The HDZP pulse-power supply system is illustrated in Fig. 15.

Reference

1. R. A. Fitch, "Marx and Marx-Like High-Voltage Generators," Maxwell Labs, Inc., IEEE Trans. on Nucl. Sci. NS-18, 4 (1971).

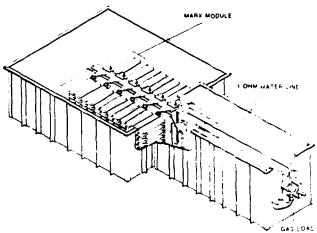


Fig. 15. Illustration of HDZP pulse-power supply system.